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Fermi level pinning study at the surface of GaP nanowires

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Semiconductor nanowires (NWs) are prospective building blocks for next generation nanoscale electronic devices. In this case, understanding NWs transport properties is of great importance. It is well known, that surface effects in quasi one-dimensional nanostructures are strong due to high surface to volume ratio. In particular, surface Fermi level pinning in NWs leads to a surface band bending and to a formation of the near surface depleted area. Such a depletion decreases conductivity of the NW. Width of the depletion area is governed by doping level, NW diameter and position of Fermi level pinning. To quantitatively analyze transport properties of the GaP NWs, one should obtain a position of the surface Fermi level pinning (work function). This parameter can be measured with Kelvin probe microscopy, as was reported previously with III-As NWs [1]. Worth noting, that GaP NWs can be grown with wurtzite (WZ) crystal structure. Such NWs draw an attention due to quasi direct band gap and possible optoelectronic applications. However, surface electronic properties of the WZ GaP NWs are not sufficiently studied. The aim of this work is to measure a position of the surface Fermi level pinning in WZ and zinc blende (ZB) GaP NWs.

The studied undoped gallium phosphide NWs were grown using molecular beam epitaxy on (111) silicon substrate. The NWs possess average length of approximately 5 μm and tapered shape with the diameter decreased from about 350 nm near the base to about 150 nm near the top. TEM study revealed that NWs had ZB crystal structure with 500 nm WZ insert near the tip. However, the very end of the NW also exhibited ZB structure. The formation of WZ segments in the NW top part is strongly related with the catalytic droplet consumption during Ga-limited growth regime and subsequent changes of the droplet contact angle promoting GaP nucleation at the triple phase (vapor-liquid-solid) line.

The Fermi level pinning position was determined by amplitude-modulated Kelvin probe force microscopy (AM-KPFM). At each scanning point the surface potential given by $V_s = \Phi_{tip} - \Phi_{sample}$ is measured as well as topography. Φ_{tip} and Φ_{sample} are the work functions of AFM tip and sample surface respectively. Before each measurement the work function of the probe was calibrated using freshly cleaved highly oriented pyrolytic graphite (HOPG), whose work function (Φ_{HOPG}) is well defined as 4.48 eV [2]. Then the work function Φ_s can be expressed as $\Phi_s = 4.48 + (V_{HOPG} - V_s)/e$, where V_{HOPG} is the surface potential of the HOPG measured by the same probe as V_s, and e is the electronic charge.

NWs were separated from the growth substrate and dispersed on silicon substrate for AFM measurements. KPFM mapping of a single NW revealed the difference between WZ and ZB GaP work function: a 500 nm region between its very end and middle region demonstrated lower surface potential. The position of the decreased potential region is in a perfect agreement with the location of WZ insert obtained upon TEM images analysis. Using the abovementioned formulas, WZ and ZB GaP work function were calculated to be 4.2 and 4.18 eV respectively. As the value of electron affinity in GaP is 3.08 eV, one can conclude that the surface Fermi level is in the middle of bandgap.

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